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SIGNAL SUBSPACE PROCESSING OF UNCALIBRATED MTD-SARs

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SIGNAL SUBSPACE PROCESSING OF UNCALIBRATED MTD-SARS

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1. Overview

This document describes the progress on the work performed for "Signal Subspace processing of Uncalibrated MTD-SARs," under Contract N00014-97-1-0966 for the Office of Naval Research for the period ending on 9/30/99.

The main achievement of our efforts in this period was to test the proposed signal subspace using realistic Displaced Phase Center Array (DPCA) SAR data. The SAR data were part of a four-channel DPCA database at X band (spotlight mode); the data were provided by the Air Force Research Laboratory at Wright Patterson Base, Ohio. The DPCA-SAR data were collected over a scene that contained various moving and stationary targets on a clear land; there were also moving and stationary targets near an area with man-made structures and dense trees. The data were originally collected for processing through conventional Ground Moving Target Indicator (GMTI) methods. However, Our processing was the first attempt to coherently combine the entire slow-time domain data (approximately 4800 pulses taken over 5 degrees of look angle) for GMTI.

A non-overlapping block-based implementation of the signal subspace algorithm was used for processing of the DPCA. Our preliminary results indicate that the proposed signal subspace method can overcome the miscalibration between the two channels of the DPCA over the entire slow-time period, and provide a reliable statistic for GMTI on both a clear land and a foliage region. The measured SAR data were originally collected for processing via the polar format reconstruction. This document also provides the description of a method used for converting polar format (motion compensated phase history) data into a database that is suitable for error-free wavefront reconstruction; the resultant wavefront reconstruction SAR images are superior to those obtained via polar format processing.

2. SAR Wavefront Reconstruction Using Motion Compensated Phase History (Polar Format) Data

The imaging algorithm that we use for SAR image formation is based on a multidimensional signal analysis of the imaging system that does not make approximations in the manner microwave propagation is modeled. This is a new SAR imaging method, known as the SAR wavefront reconstruction that was introduced about ten years ago, that provides

high-resolution and accurate coherent target information. Meanwhile, in the past thirty years an extensive theoretical and practical knowledge base has been shaped by the SAR polar format imaging that is based on approximations; some of these concepts are either incorrect or not applicable when viewed in the framework of the modern high-resolution SAR wavefront reconstruction.

A prominent example is encountered in X band spotlight SAR systems with a relatively large, e.g., 30-degree look angle. Based on the polar format processing, it is sufficient to acquire about 30,000 slow-time samples for this SAR system. However, based on the SAR wavefront reconstruction, the user should acquire and process more than 150,000 slow-time samples for alias-free imaging. Yet, the current operational SAR systems that acquire data based on the assumptions of the polar format processing, provide a motion compensated phase history (MCPH) data that contains only 30,000 slow-time samples.

In this case, the challenge for the user is to develop a method for converting the MCPH SAR data to alias-free SAR data, and form high-resolution images from the resultant database via the SAR wavefront reconstruction algorithm. We have developed such an algorithm and implemented it for an operational spotlight SAR system; the system yields 4800 slow-time samples over a 5-degree aspect angle interval (within an X band baseband bandwidth of .6 GHz). This operational SAR system provides a four channel DPCA database that we have used to examine the merits of our proposed signal subspace processing.

As far as the quality of images that are formed via this algorithm, we compared its reconstructions with the images that are formed by polar format processing. The resultant polar format processed images begin to show shift and smearing degradations for cross-range values that are about 80 meters away from the scene center. Meanwhile, the wavefront reconstruction is successful in imaging cross-range points that are over 400 meters away from the scene center. (The limit of the imaging area for the wavefront algorithm is imposed by the size of the spotlight radar beam.)

Figures 1a and 1b, respectively, show the polar format and wavefront reconstructions of the 100 m by 100 m target area at the scene center (a broadside target region); the polar format image was produced by the ERIM's CUP processor. Figures 2a and 2b are the close-ups of the above-mentioned two reconstructions; four corner reflectors are visible in this scene. Figures 3a and 3b, respectively, are the polar format and wavefront reconstructions for an off-broadside 100 m by 100 m target area. The close-ups of these reconstructions are shown in Figures 4a and 4b. Note the degradations (shift and smearing) in the polar format reconstruction.

Using the wavefront reconstruction, we were able to image an area of 450 meters (in range) by 800 meters (in cross-range). Yet, imaging such a large area posed other

difficulties in our digital implementation. The problem was associated with the size of the target function (array) that is to be imaged. (We have also encountered a similar issue in other SAR system, e.g, stripmap SAR system of P-3.) This problem is addressed next.

3. Digitally-Spotlighted Subaperture SAR Image Formation

We have examined practical issues that are associated with implementing the high-resolution stripmap/spotlight SAR imaging algorithm, known as the SAR wavefront reconstruction method, on a Distributed-Memory (DM) High Performance Computer (HPC). The SAR wavefront imaging method is an approximation-free algorithm that provides high-resolution and accurate coherent target information that is useful for advanced SAR information post-processing, e.g., automatic target recognition. However, the highly-accurate information base of the wavefront reconstruction algorithm is formed via the Fourier (FFT) processing of relatively large databases. For real-time processing in an operational SAR system, this requirement puts restrictions on the minimum size of the Random Access Memory (RAM) of the computer used for the SAR wavefront image formation.

Meanwhile, due to the limited area and cooling restrictions on a radar-carrying aircraft, the DM-HPCs are the practical choice for on board processing of SAR data. Unfortunately, in a DM-HPC, unlike a shared memory HPC, the RAM associated with each processor cannot be addressed by the other processors. In this case, the RAM available to each DM processor (currently around 64 to 128 MBytes) is not sufficient for, e.g, processing some of the recently-acquired high-resolution X band or UHF band (FOPEN) SAR data via the wavefront reconstruction algorithm.

A practical solution for the above-mentioned problem is to form lower-resolution images of subpatches of the target area from subsets of the synthetic aperture or synthetic "subapertures;" this reduces the size of the data that are processed and the FFTs used for wavefront reconstruction. Moreover, the sizes of the subpatch and subapertures can be determined a priori by the user based on the available RAM. Provided that the subaperture imaging algorithm preserves the coherent information among the lower-resolution images, the user could coherently add the lower-resolution images to form the desired high-resolution SAR image.

The challenge for this processing is i) to extract the SAR signature (or phase history data) of a given subpatch from the measured SAR data, a process that we refer to as "digital-spotlighting;" and ii) appropriate digital signal processing of subaperture SAR data that yields "calibrated" lower-resolution SAR images that can be combined coherently. We have addressed these issues via exploiting spectral (Doppler) properties of the SAR signal that is based on Gabor's wavefront reconstruction theory. The reconstructions in Figures 1a, 2a, 3a and 4a were obtained using this method.

4. GMTI Using Signal Subspace Processing of DPCA SAR Data

Next we examine the GMTI results that were obtained using a DPCA database for the X band spotlight SAR system that we examined in Figures 1-4. Figure 5a shows the SAR reconstruction of a broadside target area that was obtained with the Channel 1 SAR data of the DPCA system. The Channel 2 reconstruction resembles the image in Figure 5a (not shown here). However, the coherent or noncoherent (magnitude) difference of the images of Channels 1 and 2 would not result in nulling of the stationary targets (not shown here). Figure 5b shows the block-based signal subspace difference image; for this, we used 20 pixels by 20 pixels blocks (approximately 5 meters by 5 meters), and a filter size of 5 pixels by 5 pixels. The vertical *streaks* in Figure 5b represent the signature of the moving targets. Note that some of these streaks (i.e., moving target signatures) are not visible in the original SAR reconstruction of Figure 5a.

Figures 6a-d show a set of close-ups of the images in Figures 5a-b. In the image of Figure 6a, there is a stationary truck and a moving truck. The stationary truck is the dominant signature in Channel 1 image of Figure 6a. However, in the signal subspace difference image of Figure 6a, the moving target becomes the dominant signature.

Figure 7a shows the SAR reconstruction of an off-broadside target area that was obtained with the Channel 1 SAR data of the DPCA system; the target area is composed of a foliage region with moving targets in its surroundings. The Channel 2 reconstruction resembles the image in Figure 7a (not shown here). However, the coherent or noncoherent (magnitude) difference of the images of Channels 1 and 2 would not result in nulling of the stationary targets (not shown here). Figure 7b shows the block-based signal subspace difference image; for this, we used 20 pixels by 20 pixels blocks (approximately 5 meters by 5 meters), and a filter size of 5 pixels by 5 pixels. The vertical *streaks* in Figure 7b represent the signature of the moving targets. Note that some of these streaks (i.e., moving target signatures) are not visible in the original SAR reconstruction of Figure 7a. Figures 8a-b show a set of close-ups of the images in Figures 5a-b.

5. Planned Work

The following are the tasks we plan to follow in the continuation of our study with the DPCA SAR data:

1. Study the method using different block and filter sizes. We also plan to develop analytical tools for relate the optimal sizes of block and filter sizes to the parameters of the SAR system.

2. Use the SAR ambiguity function to estimate the speed of the moving target. This study will be followed up by a subaperture analysis of the data to determine if the

motion path of a moving target can be *tracked* in the slow-time domain.

3. Our initial investigation was based on processing a two-channel *bistatic* along-track monopulse SAR system. In the previous sections, we applied this approach to two channels of the DPCA SAR system. However, the DPCA SAR system under study provides *four* channels of data. This provides us a unique opportunity to study this *multistatic* monopulse SAR system, and determine the nature of a multistatic SAR database and how it can be exploited to improve the GMTI statistic and estimate the motion trajectory of the moving targets in the imaging scene.

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13. ABSTRACT *(Maximum 200 words)*

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